ASLV-D4/SROSS-C2 Mission

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With the orbiting of SROSS-C2 satellite by ASLV-D4 on 4 May 1994, two consecutive successful launches of ASLV have been demonstrated. Thus the various targets set for the project have been fulfilled and many technologies required for larger operational launch vehicles of ISRO have been validated. This paper provides details of ASLV-D4 mission with a general background on ASLV and summarizes the technological inputs derived.

The launch vehicle programme of ISRO envisages technology build up in a phased manner for the operational vehicles such as the Polar Satellite Launch Vehicle (PSLV) and Geostationary Satellite Launch Vehicle (GSLV) for launching Indian Remote Sensing (IRS) and Indian National Satellite System (INSAT) class of satellites respectively. Development of the smaller launch vehicles – Satellite Launch Vehicle (SLV-3) and Augmented Satellite Launch Vehicle (ASLV) – was part of this planning process. As a part of the ASLV programme, the fourth developmental flight of ASLV-D4 has been conducted. It took off from SHAR Launch Complex on 4 May 1994 at 0530 h IST, exactly at the start of the launch window after a flawless countdown. It carried a Stretched Rohini Satellite Series (SROSS) C2 satellite weighing 113.4 kg and placed it in an orbit of 437 × 938 km at an inclination of 46.3°. The performance data indicate that the launch vehicle performance matches closely with the prediction thereby fulfilling key objectives set for the ASLV-D4 mission. With the success of the last two consecutive flights, many technologies required for larger launchers like strap-on motor technology, bulbous heat shield, closed loop guidance system, real time decision have been demonstrated by ASLV, thereby fulfilling the objectives of the ASLV programme.

Table 1. ASLV at a glance

Parameter	Stage-0 (2 Strapon)	Stage-1	Stage-2	Stage-3	Stage-4
Length	10 m	10 m	6.3 m	1.6 m	0.86 m
Diameter	1 m	1 m	0.8 m	0.8 m	0.65 m
Propellant	Solid	Solid	Solid	Solid	Solid
Nozzle	Canted	Straight	Straight	Straight	Contour
Stage weight	2 × 11.55 T	11.8 T	4.4 T	1.7 T	0.51 T
Max. thrust (vac)	2 × 644 kN	687 kN	271 kN	91.4 kN	32.8 kN
Control	Secondary Injection Thrust Vector Control (SITVC), 4 Nos. of 300 kgf Bi propellant Reaction Control System (RCS)	SITVC, 8 Nos. of 50 kgf monopropellant RCS	4 Nos. of 215 kgf Bi propellant RCS, and 4 Nos. of 10 kgf Bi propellant RCS	4 Nos. each of 25 kgf, 5 kgf and 4 kgf monopropellant RCS	Spin stabilized
Separation system	Ball & socket with explosive bolts	Flexible Linear Shaped Charge (FLSC)	FLSC chord (for heatshield, merman band joint)	Ball release system	Ball release system
Navigation, Guidance and Control (NGC) system	Contains Stabilized Platform Inertial Navigation System (SPINS) and OnBoard Computers (OBC). SPINS consists of Rate Integrating Gyros (RIG), Accelerometers, Inertial Platform Module (IPM), attitude reference system and Navigation Electronics Module (NEM). OBC consists of NGC Processor (NGCP) and Stage Processing Module (SPM). NGCP contains navigation software, digital auto pilot software, guidance and flight sequencing software. During atmospheric phase, open loop guidance is followed and thereafter, closed loop guidance scheme with 'velocity to be gained' logic is used up to third stage separation.				
Vehicle electronics	Other than NGC processor and SPINS, it consists of power and instrumentation, 4th stage sequencer, S-band telemetry, telecommand, and C-band transponder.				

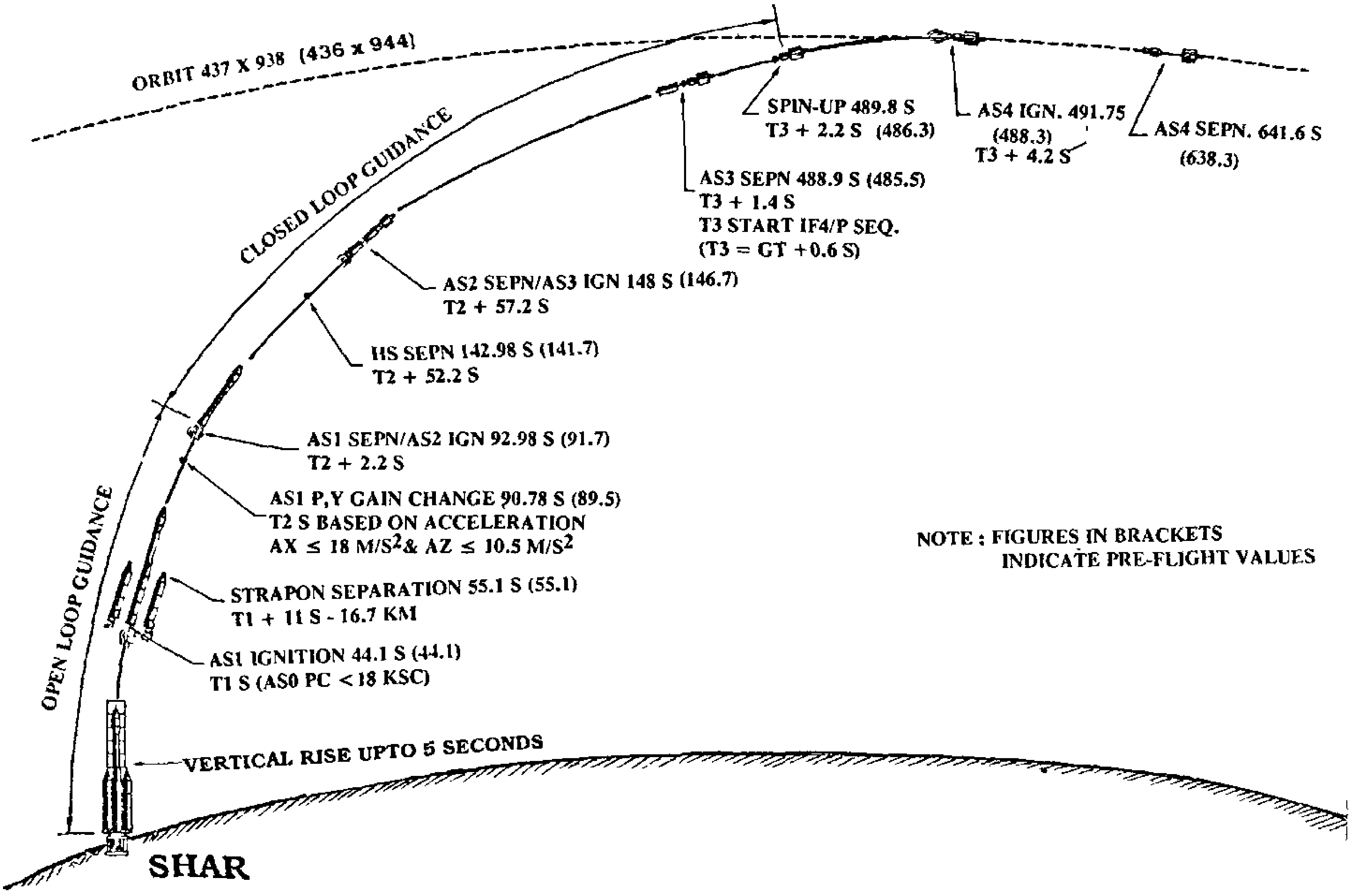

ORBIT 437 X 938 (436 x 944)
CLOSED LOOP GUIDANCE
OPEN LOOP GUIDANCE
SPIN-UP 489.8 S
T3 + 2.2 S (486.3)
AS4 IGN. 491.75
(488.3)
T3 + 4.2 S
AS4 SEPN. 641.6 S
(638.3)
AS3 SEPN 488.9 S (485.5)
T3 + 1.4 S
T3 START IF4/P SEQ.
(T3 = GT +0.6 S)
AS2 SEPN/AS3 IGN 148 S (146.7)
T2 + 57.2 S
HS SEPN 142.98 S (141.7)
T2 + 52.2 S
AS1 SEPN/AS2 IGN 92.98 S (91.7)
T2 + 2.2 S
AS1 P,Y GAIN CHANGE 90.78 S (89.5)
T2 S BASED ON ACCELERATION
AX ≤ 18 M/S2 & AZ ≤ 10.5 M/S2
NOTE : FIGURES IN BRACKETS INDICATE PRE-FLIGHT VALUES
STRAPON SEPARATION 55.1 S (55.1)
T1 + 11 S - 16.7 KM
AS1 IGNITION 44.1 S (44.1)
T1 S (AS0 PC < 18 KSC)
VERTICAL RISE UPTO 5 SECONDS
SHAR

Figure 1. Flight sequence of ASLV-D4.

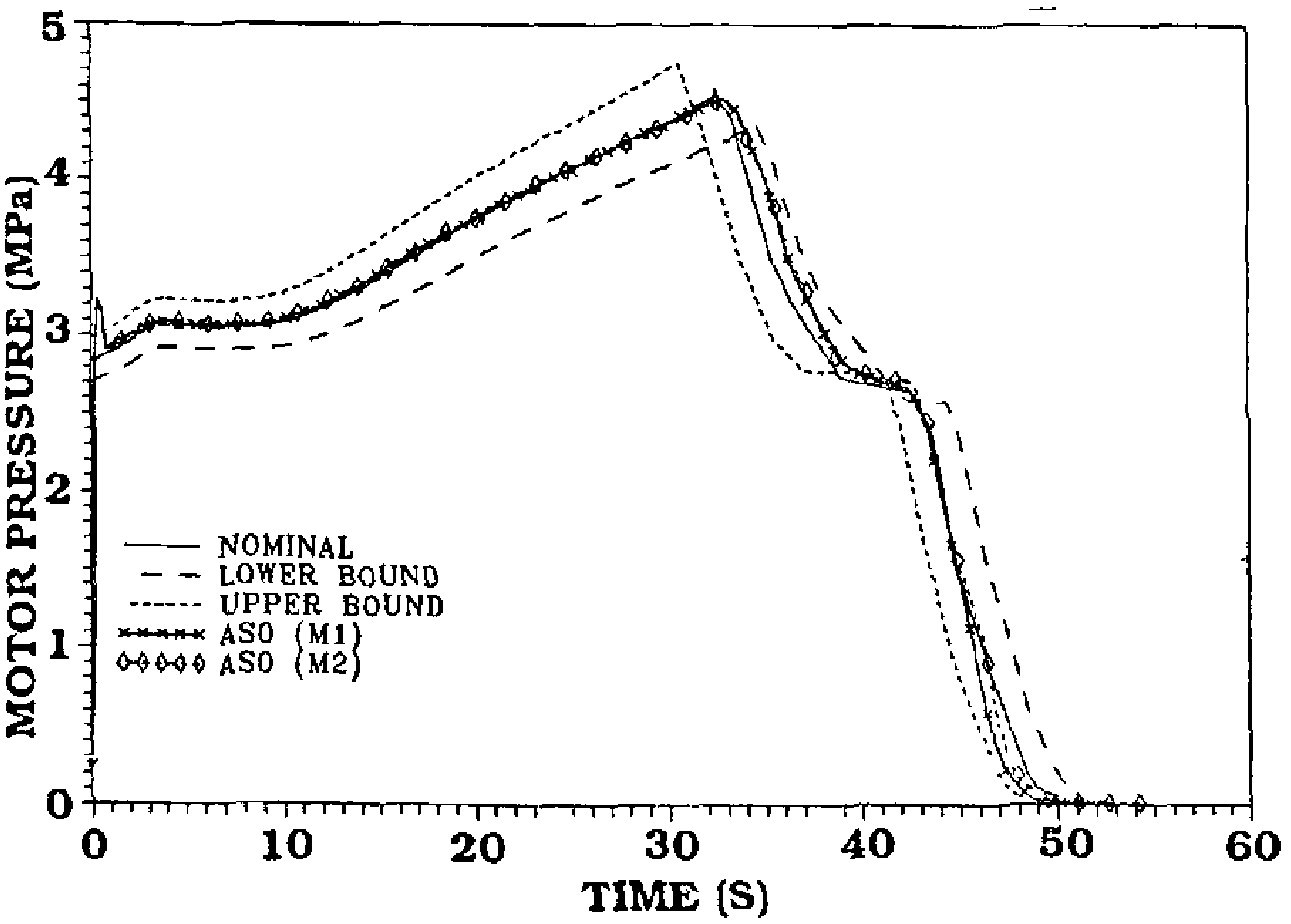


Figure 2. Strapon motor performance of ASLV-D4.

Mission objectives

To evaluate the launch vehicle performance of ASLV-D4 by placing 113.4 kg SROSS-C2 satellite in a near earth inclined orbit and to conduct the following experiments on:

- ➢ Gamma ray burst (GRB) detection in the area of astrophysics
- ➢ Retarding potential analyser (RPA) in the area of aeronomy.

A complete description of the various subsystems like structures, propulsion, control, navigation, stage auxiliary systems, avionics, aerodynamics and of the integration aspects and product assurance have been discussed in detail in ref. 1. However, a brief description of the vehicle is provided below for completeness.

Description of ASLV

ASLV is a five stage all solid satellite launch vehicle with a take-off weight of

41.8 tons and length 23.8 m and is capable of placing payloads up to 150 kg into 400 km Low Earth Orbit. The main features of ASLV are provided in Table 1.

Changes from ASLV-D3 to D4

Taking into account the ASLV-D3 and PSLV-D1 inputs, certain modifications were carried out to improve the reliability of the mission and the payload capability of the vehicle. The major modifications from ASLV-D3 are as follows:

On the launch vehicle side, the spin up system was redesigned to improve the reliability in view of the lower spin rate observed during ASLV-D3 flight. The closed loop guidance algorithm was modified to convert the additional energy that may be imparted by the lower stages into a higher perigee thus removing the circularity constraint. The onboard software was subjected to stress testing to detect and avoid computational overflow.

On the satellite front, the satellite weight has been increased from 106 kg to 113.4 kg by changing the perigee altitude from 450 km in ASLV-D3 to 400 km for D4. Due to increased weight, orbit correction capability has been incorporated by employing onboard RCS thrusters. The indigenously developed Ni–Cd batteries are used on the satellite for the first time.

In addition to the above broad changes, a number of significant changes/modifications were carried out for the ASLV-D4 Mission. The specific impulse (I_{sp}) for all the stage motors were revised based on static and flight tests database. A miniaturized version of S-band transmitter onboard in place of S-band Range and Range rate (SRRT) system was incorporated and also magnesium alloy chassis for certain packages were introduced to reduce the weight of electronic packages. Enhanced reliability was provided for the pyro systems and electrical circuits. The telemetry measurements were reduced from 253 to 189 based on the experience of previous flights. The control dead zone for AS3 coasting phase was enhanced from 1° to 2° thus increasing the dead zone and reducing the operation of the coast phase control motor and thus the propellant consumption.

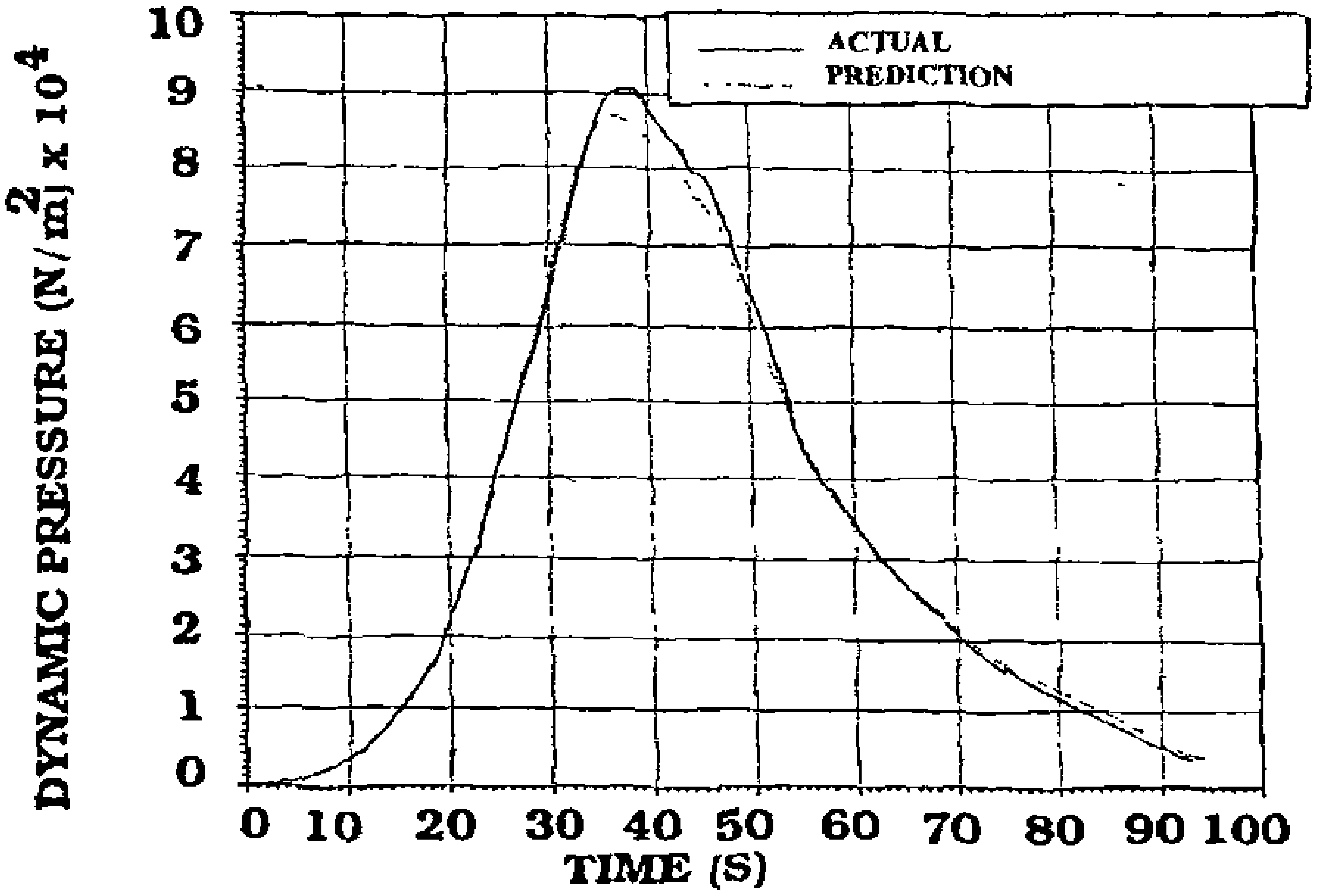


Figure 3. Dynamic pressure history of ASLV-D4.

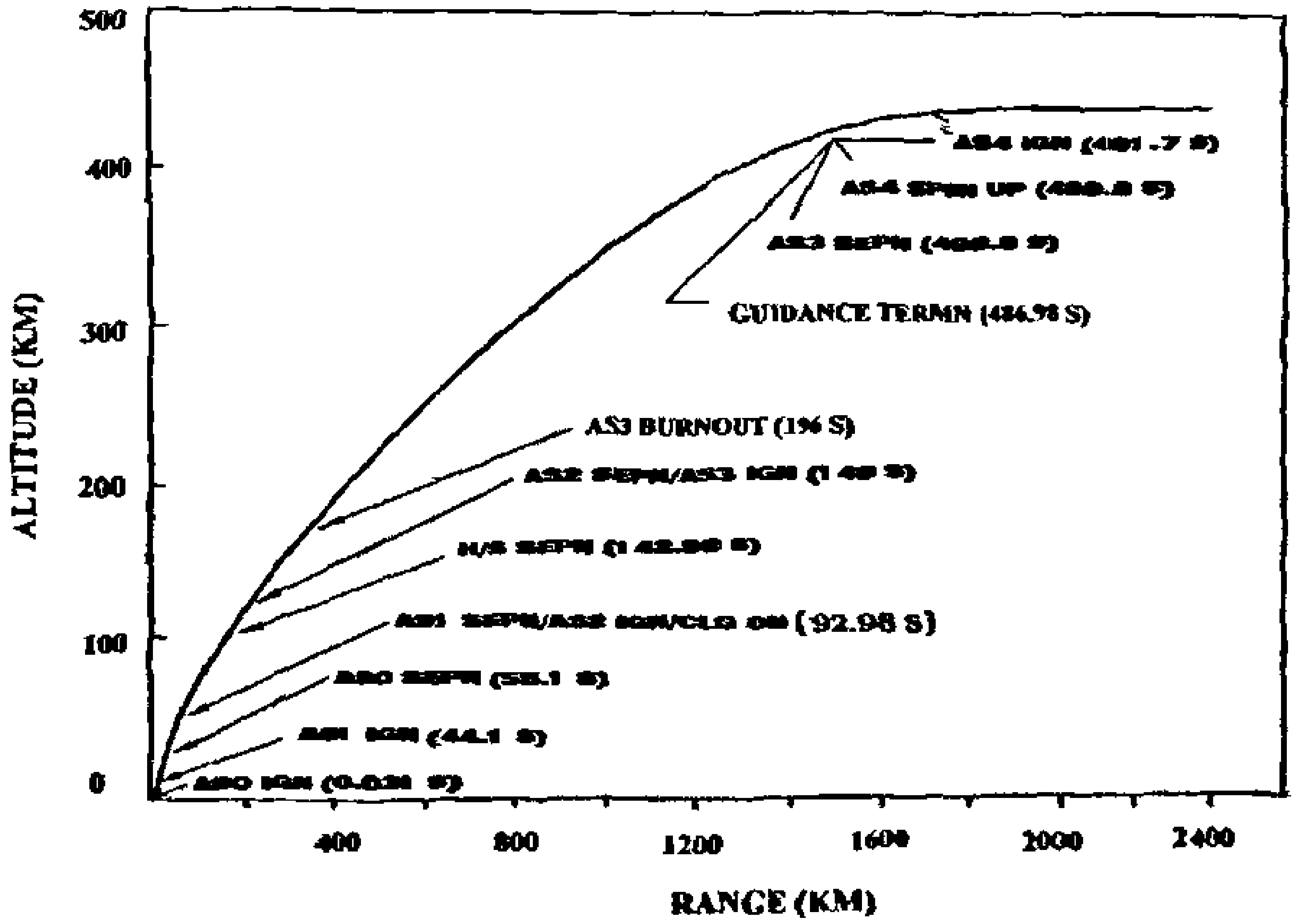


Figure 4. Range vs altitude profile.

Flight sequence

The flight sequence of ASLV-D4 mission consisted of a vertical rise for 5 s after lift-off followed by a pitch down manoeuvre along the direction of flight azimuth. Thereafter, the vehicle was guided in Open Loop Guidance (OLG) till the separation of the first stage/ignition of second stage. From this

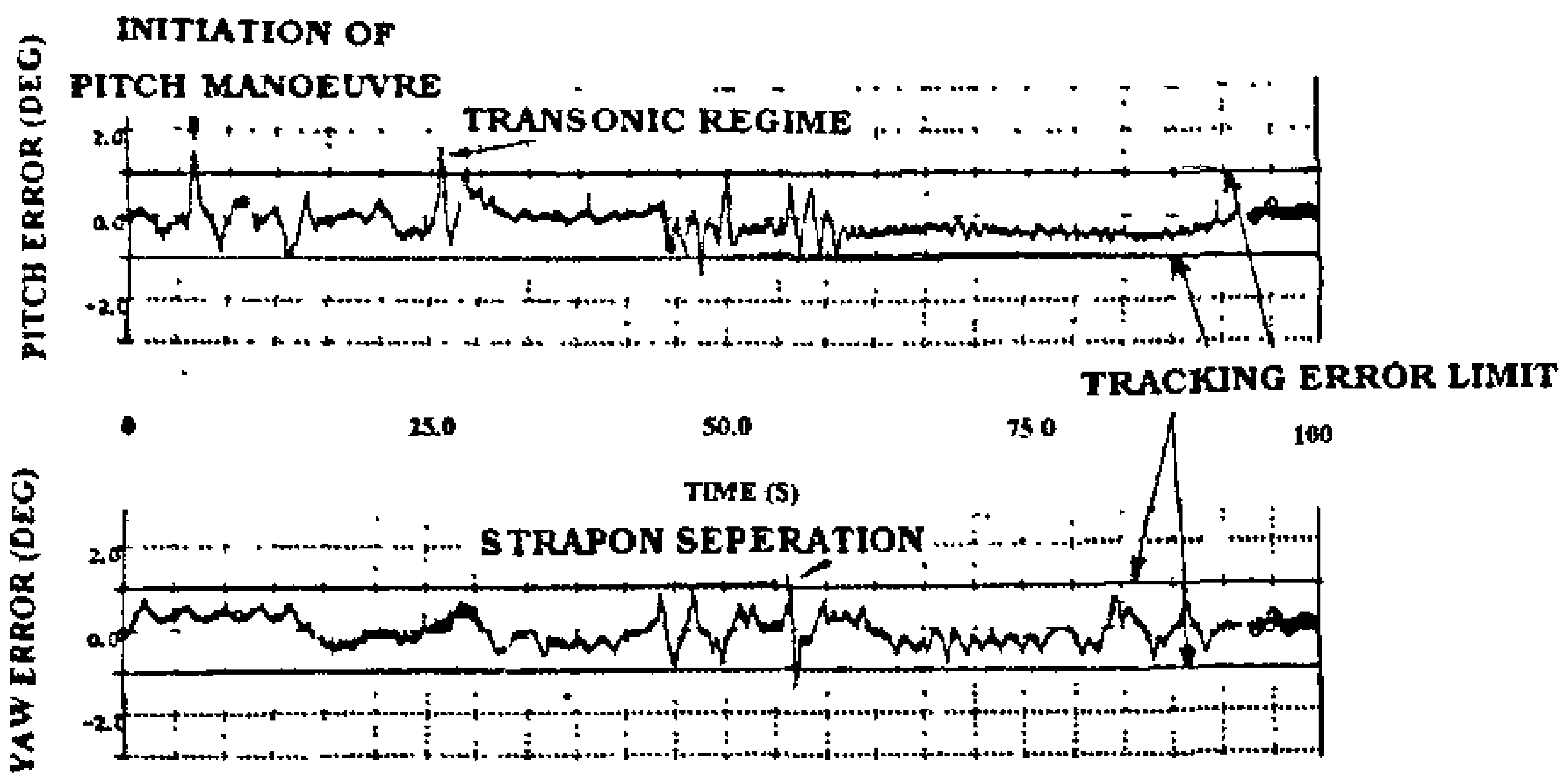
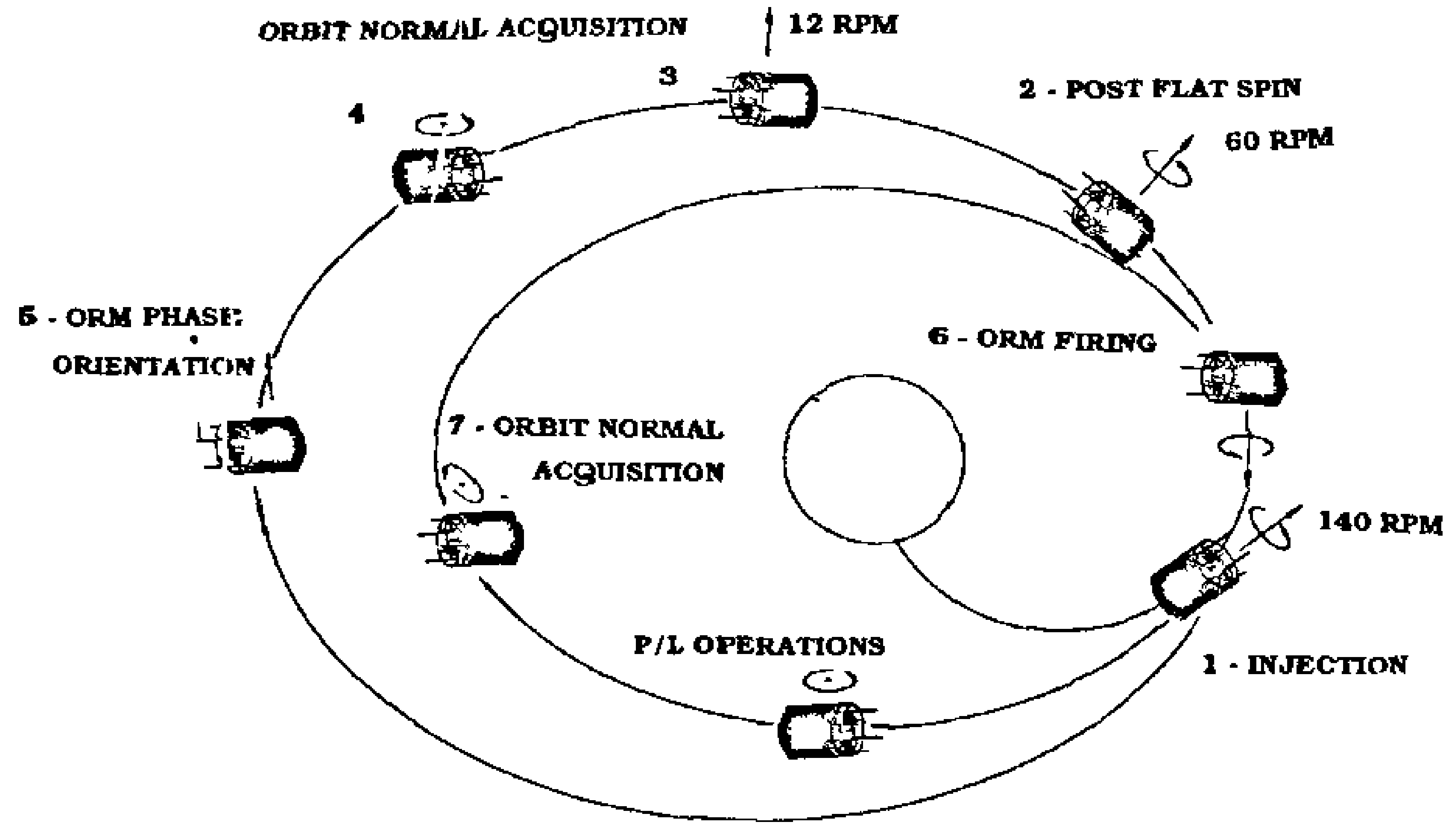


Figure 5. Pitch and yaw errors during atmospheric regime of flight.



SROSS-C2 MISSION PROFILE

Figure 6. Mission profile of SROSS-C2.

point and till the separation of the third stage (coast apogee), the vehicle was guided using Closed Loop Guidance scheme (CLG). In CLG, at every instant, the state and orientation of the vehicle is computed from the measurements of the inertial sensors provided in the Stabilized Platform Inertial Navigation System (SPINS). By knowing the present position and orientation of the vehicle, the guidance algorithm compares with the target variables (altitude, velocity magnitude and orientation) and computes the velocity to be gained still and from this, the orientation of the vehicle for the next instant is computed so as to reach the target point. Once the orientation of the vehicle that is to be commanded is known, the errors between the measured and the required are computed by the Digital Auto Pilot (DAP) and this information is given to the control systems to cause a change in the thrust vector. In ASLV, after the separation of the third stage, stabilization of the combined 4th stage and the satellite is achieved by spinning the combination at 140 rpm using spin rockets. After the injection of the satellite into orbit and separation from the 4th stage, the spin reduction is carried out by the satellite system.

The Real Time Decision (RTD) was introduced in ASLV to sequence the inflight events like stage ignition and separations. The primary criterion is to avoid no control zone during AS0/AS1 and AS1/AS2 critical transition zones The no control zone may arise due to ineffectiveness of the Secondary Injection Thrust Vector Control (SITVC) systems during tail-off regime of the respective stage motors. For AS0/AS1, this critical phase occurs during the atmospheric regime where the lack of control has to be avoided whereas for the AS1/AS2 transition zone, due to higher tail-off thrust, the collision of the separated but still thrusting stage with the preceding stage has to be avoided Hence, pre-fixed event times as carried out in the case of SLV-3 and the first two flights of ASLV had to be modified by Real Time Decision. The RTD sets the flight event based on the comparison of the sensed motor pressure values for AS0/AS1 transition and the acceleration for AS1/AS2 with the preset values. The RTD actuation for each stage is enabled at a particular time during each phase called the 'window in' time and also has a 'default or window out time' to initiate further actions in case the RTD fails. Thereafter, the rest of the actions like control-off of the spent motor, separation initiation and ignition of the preceding stage, etc. are controlled in a time line with respect to the RTD event. The fixing of these parameters is done after extensive trajectory simulations considering worst case simulations.

ASLV-D4 flight performance

The flight sequence of ASLV-D4 Mission with the nominal predicted event times and the one realized during flight is given in Figure 1. All the events during flight have occurred according to the prediction. The strapon motors have provided identical performance with similar tail off characteristics (Figure 2). To have the performance of strap-on motors within a close band and to have a closer prediction of the flight motor, the production of batch motor casting of 3 motors and static testing of one of them prior to flight was started before ASLV-D3 flight. The dynamic pressure which is one of the design factors to keep the aero loads within the design margin has followed the prediction during flight (Figure 3). The ASLV-D4 flight has followed the pre-flight prediction up to injection but for the higher velocity of

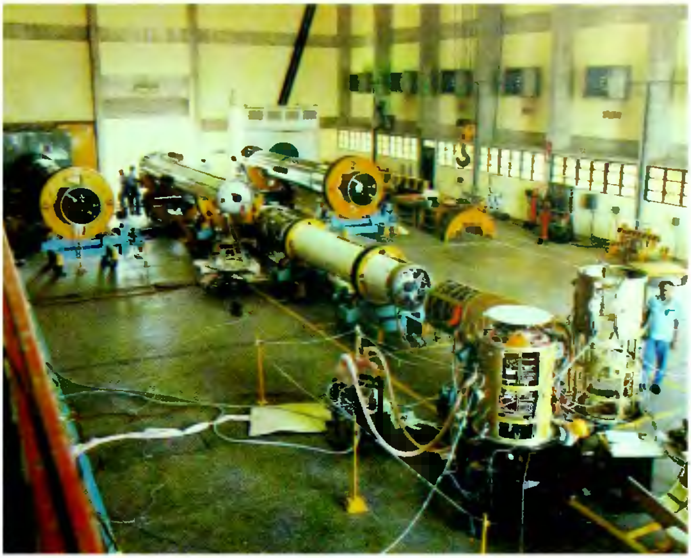


Figure 7. Phase-2 electrical checks of the complete vehicle

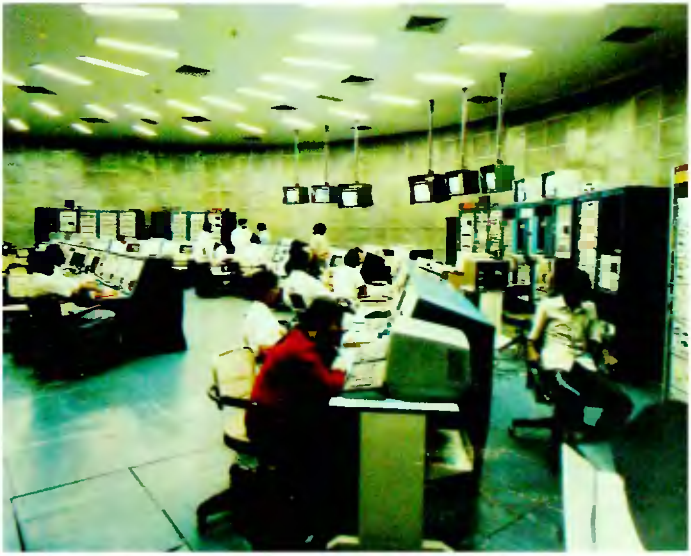


Figure 8. Interior view of the Block House housing the vehicle consoles and check-out computers

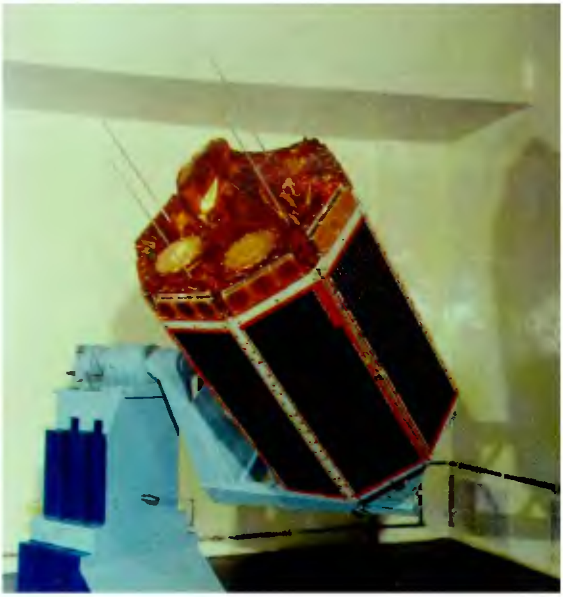


Figure 9. Fully assembled SROSS-C2 satellite.

about 50 m/s obtained at the third stage burnout. This over-performance of the stage motors was anticipated before the mission itself based on the performance database and subscale motor tests and lower drag anticipated during atmospheric regime of flight. The final orbit obtained matches with the orbit predicted with this over-performance. The fourth stage motor, AS4, has performed as predicted is evident from the close matching of the orbit predicted based on the performance up to the third stage burnout and assuming an ideal performance of 4th stage and the Preliminary Orbit Determination (POD) made soon after the flight based on the tracking data available from Car Nicobar (CAN). In this mission, for the first time the vehicle has been tracked up to a range of nearly 1800 km by the tracking systems. Due to this, the 4th stage motor pressures were available in real time at the launch base, confirming the normal performance of the stage motor. Figure 4 provides the range vs altitude obtained during mission.

Throughout the flight, the vehicle was under control. The control motor propellant consumption for the SITVC systems in flight is observed to be less than 20% and for the strap-on motor and first stage RCS motors, it is less than 15% and for second and third stages less than 35%. The errors in pitch and yaw during the critical atmospheric phase of flight is provided in Figure 5.

SROSS-C2 satellite mission profile

ASLV-D4 mission carried a SROSS-C2 satellite weighing 113.4 kg consisting of two scientific payloads as explained in the mission objectives. SROSS is of octagonal prismoidal in shape. To meet the specific requirements of the payloads, the satellite is configured as a spinner with its spin axis oriented normal to the orbital plane. Eight body mounted solar panels on the satellite are used to generate 50 W of electrical power backed up by an 18 Ah battery. The telemetry, tracking and command links are operated in S-band with a redundancy in VHF-band for telemetry and telecommand. Three magnetometers, one sun sensor, two magnetic torquers were provided for altitude and orbit control functions. In addition, the satellite employs hydrazine RCS with six thrusters to trim the orbit. The RCS thrusters are planned to be used to adjust the orbit suiting the scientific experiments. The GRB detector is to monitor celestial gamma ray in 20 keV to 3 MeV energy range. The RPA will measure densities, temperatures and flux characteristics of ionospheric electrons and ions in thermal and suprathermal region. The satellite mission profile is given in Figure 6.

Mission management

The total mission management involved in a launch can be classified into pre-launch, launch phase and post-launch. The pre-launch mission activities include the vehicle subsystem checks (Phase-1 checks) at the Vehicle Integration Building (VIB) after they are received at the launch complex. Before the vehicle subsystems are moved to launch pad, they are electrically connected and a Phase-2 check is carried out on the vehicle to ensure proper working of all the systems (Figure 7). This is followed by vehicle integration at the Mobile Service Tower (MST). After the vehicle is integrated, assembly of the satellite and the heat shield are carried out. The overall checks on the launch vehicle and satellite is conducted in the next phase called the Phase-3 test, involving the ground stations also. The vehicle-related activities are carried out from Block House (BH) (Figure 8). This building is designed for explosion proof as it is very near to launch pad. The final vehicle operations which starts 47 h before the launch are coordinated from the BH which houses different vehicle subsystem consoles, safety and power consoles and the vehicle check out computers which carry out the automated vehicle checkout during the last 10 min before launch. The important events on the launch vehicle prior to launch like warm up sequence

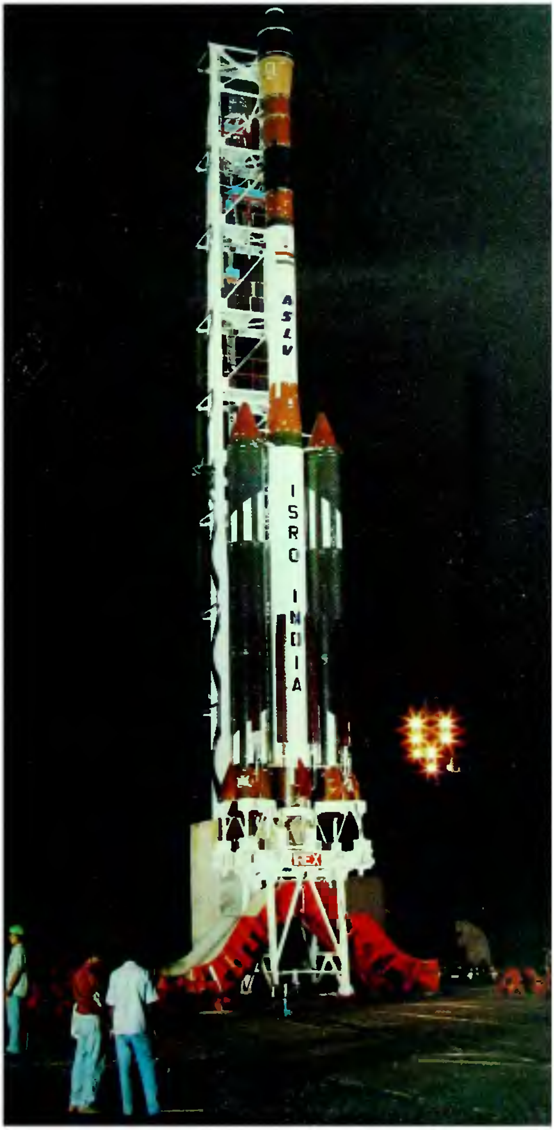


Figure 10. Fully assembled ASLV-D4 vehicle carrying SROSS-C2 satellite.

of the various control motors are monitored from here to ensure their proper functioning during flight.

The overall mission activities covering launch vehicle, range, telemetry, tracking and telecommand (TTC) network and satellite are monitored during flight from the Mission Control Centre (MCC) situated at a distance of 10 km from launch pad. The launch base in addition to providing support for integration and launch, also supports the mission from lift-off till injection to monitor the vehicle in flight and also from the point of ensuring a safe flight and to make a detailed analysis from the telemetered data after the flight. Before the mission, all the ground stations like tracking radars, telemetry, telecommand and other auxiliary support systems like CCTV, range timing and a host of other down range TTC stations undergo a TTC network simulation exercise.

Figure 9 shows the fully assembled SROSS-C2 satellite. The fully assembled ASLV-D4 vehicle carrying SROSS-C2 satellite is shown in Figure 10.

Technological inputs

As enumerated earlier, with a host of new technologies getting tested/qualified by the two successive flights of ASLV, it has already served as a flying test bed for ISRO's future launch vehicle programme. Though, the first two missions of ASLV, ASLV-D1 and D2 ended up in failure, the detailed post-flight analysis enabled ISRO to understand better the various aspects of launch vehicle including the aerodynamics–control–structure interaction for the future flights of PSLV and GSLV. The various technological inputs provided by ASLV mission are summarized below.

Technical inputs from ASLV

- Strapon technology
- Inertial navigation technology
- Closed loop guidance technology
- Microprocessor based onboard computer
- Onboard real time decision making
- Design inputs
  - *Aero-structure-control interaction*
  - *Acoustic levels*
  - *Transonic buffeting*

- S-band TTC technology for launch vehicle
- Vertical integration technology
- Metallic heat shield with bulbous shape

Concluding remarks

The ASLV project was started in June 1982 towards launching two developmental flights In January 1987, the ASLV continuation project was approved for two more flights. Four developmental flights and significant infrastructure have been realized by the project and the project has contributed in the various areas of launch vehicle technology Apart from various centres of ISRO, many Indian industries have contributed towards realizing this vehicle and manufacturing the various subsystems Also national R&D laboratories and science institutions have taken part in the design reviews and analysis.

The second consecutive successful flight of ASLV has further validated ISRO's competence in the design of a complex launch system. ASLV as a flying test bed, enabled proving a number of technologies. Decision on future of ASLV will depend on requirement of this class of satellites and any further testing of new technologies.

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1 Reddy, M B and Dev, M S R, *Curr Sci*, 1994, 66, 408–416

2 ASLV-D4 Mission – Preflight Performance Data Book, ASLV-C Project, April, 1994

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